Built environment, physical activity and diabetes

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Type-2 diabetes, which has emerged as a global epidemic in recent years, is strongly related to lifestyle and economic change. The built environment (BE) influences lifestyle factors such as physical activity and diet. Evidence shows that individuals who live in neighbourhoods with the availability of destinations for physical activity within walking/cycling distance are more likely to engage in the same and thereby improve their health. Walking can be increased in neighbourhoods by providing useable and unencroached pedestrian pathways, undertaking motor-traffic reduction strategies, improved perceived neighbourhood safety, increasing good street connectivity, parks, green space, playgrounds and recreation areas. Thus for the BE to positively influence health outcomes and be made more activity-friendly, requires combined efforts of health professionals and stakeholders in the Government as well as the private sector.

Keywords: Built environment, diet, diabetes, health outcome, physical activity.

Introduction

ACCORDING to the World Health Organization (WHO), diabetes mellitus is considered as 'an apparent epidemic which is strongly related to lifestyle and economic change'[1]. Type-2 diabetes mellitus (T2DM) is the most common type of diabetes present worldwide. It is characterized by insulin resistance with relative insulin deficiency which can progress over time. This type of diabetes is genetically transmitted with polygenic inheritance. It has a strong link with obesity, and thus there is an important role for lifestyle/environmental factors such as diet and physical activity (PA) in the prevention and control of the disease. T2DM has emerged as a global epidemic in recent years, with a disproportionately higher number of individuals with the disorder in low and middle income countries[2,3]. The impact of diabetes on both the health of individuals and on the healthcare systems, is almost entirely due to the long-term 'complications' of the disease which affects almost every system in the body, in particular the eyes, kidneys, heart, feet and nerves. Diabetes-related vascular complications can be broadly classified into microvascular complications – affecting the retina (diabetic retinopathy, DR), kidney (diabetic nephropathy) and the peripheral nerves (diabetic neuropathy) and macrovascular – affecting the heart (cardiovascular disease), brain (cerebrovascular disease) and the peripheral arteries (peripheral vascular disease).

The prime drivers of the increase in diabetes prevalence are the rapid demographic and epidemiological transitions occurring in developing countries as a consequence of increasing urbanization, industrialization and economic liberalization[4]. In recent times, most countries have experienced great transitions in social structures, economics, politics, education and home environments leading to the global diabetes epidemic. Lifestyle or behavioural factors, defined as an aggregation of personal decisions (i.e. over which the individual has control) that can be considered to contribute to, or cause, illness or death, play a major role in the development of T2DM[5]. Diabetes occurs due to the synergistic effects of lifestyle factors such as physical inactivity, unhealthy diet, tobacco consumption, harmful use of alcohol, lack of sleep and increased stress. The greatest effects of these behavioural risk factors are observed increasingly in developing countries, mirroring underlying socio-economic determinants (poverty, illiteracy, social inequality and poor health infrastructure). In addition, development of T2DM is also influenced by the built environment (BE), i.e. 'the environments that are modified by humans, including homes, schools, workplaces, highways, urban sprawls, accessibility to amenities, leisure, and pollution'[6].

T2DM shares its risk factors with other non-communicable diseases (NCDs). WHO estimates that among the causes of NCDs, genetic factors contribute 30%, environment 5%, social factors 15%, behavioural factors 40% and healthcare related factors 10%. Several of these risk factors are modifiable, whereas others like age and genetic make-up are non-modifiable. If the three major modifiable risk factors (physical inactivity, unhealthy diet and tobacco use) are eliminated and the intermediate modifiable risk factors (elevated blood pressure, blood lipids and obesity) are controlled, more than 80% of T2DM and cardiovascular disease can be prevented[7].

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Few studies have estimated the contribution of various risk factors to the population-attributable risk (PAR) for diabetes[8,9]. Hu *et al.*[9], during 16 years of follow-up on 84,941 female nurses, free of diagnosed cardiovascular disease, diabetes and cancer at baseline, assessed PAR for diabetes. The combination of five risk factors, including an unfavourable diet risk score, higher body mass index, physical inactivity, smoking and alcohol use could explain 93% of all incident diabetes in their study population. In a recent study (Chennai Urban Rural Epidemiology Study, CURES) conducted among an urban South Indian population, the contribution of various modifiable risk factors to PAR for diabetes was evaluated in a cohort of 1376 individuals who were free of diabetes at baseline and were followed up for 10 years[8]. The combination of five risk factors (obesity, physical inactivity, unfavourable diet risk score, hypertriglyceridaemia and low HDL cholesterol) could explain 80.7% of all incident diabetes. Interestingly, improvement in diet and levels of PA alone could reduce the prevalence of diabetes by 50% (ref. 8). These studies suggests that modifying the easily identifiable risk factors could prevent the majority of cases of incident diabetes in the population.

Burden of diabetes

Globally, the number of individuals with T2DM is increasing rapidly in both developed and developing countries. Given that diabetes is a major cause of mortality and morbidity leading to increased healthcare expenditure, addressing this chronic disorder represents one of the greatest global health challenges[10]. According to the International Diabetes Federation (IDF), one in 11 adults had diabetes in 2015, accounting for 415 million people affected by the disease worldwide. This number is further expected to reach 642 million by the year 2040, with three-quarter of all diabetes cases occurring in low- to middle-income countries[11]. The global prevalence of diabetes is 8.8% (ref. 11) and it has become the most frequently encountered metabolic disorder in the world. The overall increase in the prevalence of diabetes has been steeper in low- and middle-income countries than in affluent, high-income countries[12]. In addition, approximately 46.5% of diabetes cases are undiagnosed worldwide[11]. Diabetes which was considered to be a mild disorder of the aged during the last three decades has now become one of the major causes of morbidity and mortality affecting young and middle-aged individuals worldwide[13].

A recently published pooled analysis of 751 population-based studies with 4.4 million participants reported that the number of adults with diabetes in the world has increased from 108 million in 1980 to 422 million in 2014. The analysis also showed that East Asia and South Asia had the largest rise in terms of absolute numbers, and also the largest number of people with diabetes in 2014: 106 million and 86 million respectively (28.5% due to the rise in prevalence, 39.7% due to population growth and ageing, and 31.8% due to interaction of these two factors)[14].

Figure 1 shows the increasing number of individuals with diabetes across the globe in the seven regions of the IDF[11]. South Asia is one of the epicentres of the diabetes epidemic. The IDF estimates in 2015 indicate that over 78 million of the adult population in Southeast Asia (SEA) have diabetes. It is also estimated that over 86% of the adults in SEA live in India. The diabetes rates in SEA vary from 3.3% in Nepal to 10% in India[11]. Of the top ten countries listed by IDF in 2015, in terms of the number of diabetic individuals, eight are developing countries, namely China (109.6 million), India (69.2 million), Brazil (14.3 million), the Russian Federation (12.1 million), Mexico (11.5 million), Indonesia (10.0 million), Egypt (7.8 million) and Bangladesh (7.1 million). Currently, China has the highest number of people with diabetes in the world, and these numbers are expected to increase to 150.7 million by 2040. The corresponding figure for India is 123.5 million by the year 2040 (ref. 11). The prevalence of diabetes and its adverse health effects have increased more rapidly in South Asia than in any other region of the world[15].

In India, studies have shown that the prevalence of diabetes is growing rapidly in both urban and rural areas and in the peri-urban population, the prevalence is found to be midway between the rural and urban populations[16,17]. Figure 2 presents the IDF estimates and projections for diabetes (20–79 years age group) in India using epidemiological studies conducted from 2000 to 2015 (refs 11, 18–23). Currently, over 69 million Indians have diabetes and approximately 90% of them have T2DM. Data from different regions have largely confirmed these projections. Mostly single-centre studies have been conducted across India to assess the prevalence of diabetes[16].

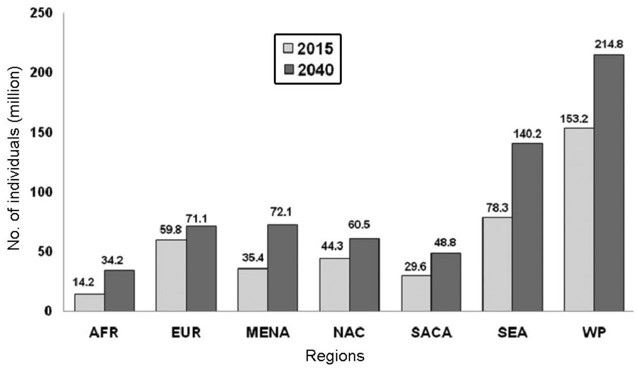

Figure 1. Increasing number of individuals with diabetes across the Globe (in millions)[11]. AFR, Africa; EUR, Europe, Mena, Middle East and North Africa; NAC, North America and the Caribbean; SACA, South and Central America; South East Asia; WP, Western Pacific.

However, only a few multi-centric studies such as the Indian Council of Medical Research (ICMR) studies[24,25], National Urban Diabetes Survey (NUDS)[26], The Prevalence of Diabetes in India Study (PODIS)[27], WHO–ICMR NCD risk factor surveillance study[28] and the Indian Council of Medical Research-India Diabetes (ICMR-INDIAB) study[29,30] have been conducted.

The recent ICMR-INDIAB study, which is a nationally representative epidemiological survey, reported the prevalence of diabetes (both known and newly diagnosed) to be 10.4% in Tamil Nadu (TN) (urban – 13.7; rural – 7.8%), 8.4% in Maharashtra (urban – 10.9%; rural – 6.5%), 5.3% in Jharkhand (urban – 13.5%; rural – 3.0%), and 13.6% in Chandigarh (urban – 14.2%; rural – 8.3%). The overall number of people with diabetes in India in 2011 was estimated to be 62.4 million (ref. 30), this was similar to the IDF projection for India, which gave a figure of 61.3 million people with diabetes in the country in the age group of 20–79 years (ref. 22).

In addition to the burden of diabetes, India has a large pool of prediabetic individuals who have a high potential to develop T2DM. The prevalence of prediabetes among urban residents of TN, Maharashtra, Jharkhand and Chandigarh in the ICMR-INDIAB study was reported to be 9.8%, 15.2%, 10.7% and 14.5% and that among rural residents 7.1%, 11.1%, 7.4% and 14.7% respectively. When extrapolated to the whole country, these estimates translated to 77.2 million with prediabetes in India in 2011 (ref. 30). Recently, the Centre for cArdio-metabolic Risk Reduction in South Asia (CARRS) Study conducted in 16,288 subjects (Chennai: 6906, Delhi: 5365 and Karachi: 4017) reported that 47.3–73.1% of the population had either diabetes or prediabetes. The prevalence of diabetes and prediabetes was 22.8% and 37.9% in Chennai; 25.2% and 47.6% in Delhi, and 16.3% and 31.1% in Karachi respectively[31].

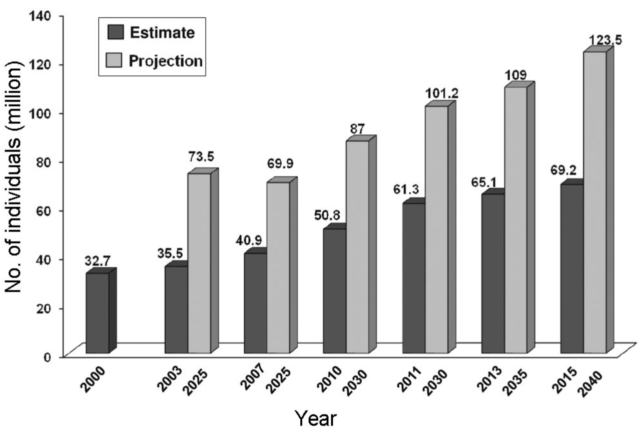

Figure 2. International Diabetes Federation estimates and projections for diabetes (20–79 years age group) in India[11,18–23].

In addition to the increasing prevalence of this disease, Asian Indians also have one of the highest incidence rates of diabetes, with rapid conversion from normoglycaemia to dysglycaemia[32]. The 10-year follow-up of CURES reported the incidence rates of diabetes, prediabetes, and any dysglycaemia to be 22.2, 29.5, and 51.7 per 1000 person-years respectively. The same study reported that among those with normal glucose tolerance, 19.4% converted to diabetes and 25.7% to prediabetes, giving an overall conversion rate to dysglycaemia of 45.1%. Among those with prediabetes, 58.9% converted to diabetes[32]. These findings increase the possibility of a more aggressive course of the underlying pathophysiological process of T2DM in Asian Indians. Earlier studies have shown that Asian Indians tend to have higher plasma levels of insulin[33] and increased insulin resistance compared to Caucasians[34]. A recent study has shown that β-cell dysfunction occurs very early in the natural history of T2DM in Asian Indians[35]. This combination of increased insulin resistance with rapidly failing β-cells may explain the faster transition to dysglycaemia in the Asian Indian population.

Available data also suggest that the susceptibility of Asian Indians to the complications of diabetes mellitus differs from that of the Western population[36–39]. The vascular complications of T2DM account for the majority of the social and economic burden. The long-term complications associated with T2DM carry a tremendous burden in terms of both morbidity and mortality. Approximately 50% of patients with T2DM die prematurely due to cardiovascular complications and approximately 10% die due to renal failure. Global excess mortality attributable to diabetes in adults was estimated to be 3.8 million deaths[40].

Physical inactivity – a risk factor for diabetes

The American Diabetes Association (ADA) has defined PA as bodily movement produced by the contraction of skeletal muscle that requires energy expenditure in excess of resting energy expenditure, while exercise is defined as a subset of PA that is planned, structured and consists of repetitive bodily movement performed to improve or maintain one or more components of physical fitness[41]. In addition to reduced PA, sedentary behaviour, defined as engaging in activities at the resting level of energy expenditure, which includes sleeping, sitting, lying down, computer time and viewing television, also plays an important role in the etiology of T2DM[42,43]. WHO's 'global recommendations on physical activity for health' for the prevention of NCDs emphasize the need for at least 150 min of moderate-intensity aerobic PA throughout the week or at least 75 min of vigorous-intensity aerobic PA throughout the week[44].

Physical inactivity is an important public health concern given its harmful impact on the health of the population and has been associated with higher all-cause mortality[45]. It has been identified as the fourth leading risk factor for mortality and contributes to 6% of deaths globally[46]. The transition from traditional to modern life has several health hazards, including the development of NCDs like diabetes. This is because, individuals who earlier had vigorous occupations in rural areas get employed in sedentary occupations in urban areas. Moreover, they now have access to urban facilities like mechanized transport and appliances for household chores, thus further decreasing PA levels. Strong evidence shows that physical inactivity increases the risk of many adverse health conditions, including the major NCDs (T2DM, CHD, stroke, cancer) and shortens life expectancy, which presents a major public health problem globally. Too much sitting and other sedentary activities can increase the risk of NCDs. Lee *et al.*[47] estimate that physical inactivity is accountable for between 6% and 10% of the major NCDs, including coronary heart disease (6.0%), T2DM (7.0%), breast cancer (10.0%) and colon cancer (10.0%) and by eliminating physical inactivity, life expectancy of the world's population may be expected to increase by 0.68 years. Physical inactivity is also responsible for substantial economic burden in high-income countries (80.8% of healthcare costs and 60.4% of indirect costs)[48].

Being physically active plays a vital role in ensuring health and well-being. The benefits of exercise extend far beyond weight management. A large body of evidence has clearly documented the many health benefits of PA (Table 1). PA benefits many parts of the body – heart, skeletal muscles, bones, blood (e.g. cholesterol levels), the immune system and nervous system, thus improving overall quality of life. Regular PA reduces the risk of NCDs and premature death by several biological mechanisms, and has been shown to reduce abdominal adiposity[49] as well as lipid levels by lowering triglyceride levels, increasing high density lipoprotein (HDL) cholesterol levels and decreasing low-density lipoprotein (LDL)-to-HDL ratios[50]. Regular PA also helps improve insulin sensitivity[51] and reduce stress, anxiety and depression[52]. Studies have also shown that PA reduces blood pressure[53] and systemic inflammation[54], and enhances endothelial function[55].

Despite the knowledge regarding the benefits of PA, a large proportion of the world's population remains physically inactive. Urbanization has resulted in several environmental factors which discourage participation in PA, particularly in the transport and occupational domains. In developing countries, less than a quarter of the population exercises regularly[56]. Wide variations in the prevalence of PA have been reported in various countries. A WHO global report published in 2002, showed that 17.7% of the global population aged ≥15 years was not engaged in any kind of PA[57], and that nearly 58% was not achieving the recommended amount of activity[58]. Hallal *et al.*[59] reported that about 31% of adults aged >15 years worldwide did not meet the recommended level of PA, and the proportion (80%) was even higher in adolescents aged 13–15 years.

The large cross-sectional World Health Survey, which was conducted in 70 countries in 2002 and 2003 by WHO reported that the prevalence of physical inactivity for Indian men was 9.3%, whereas that for women was 15.2% (ref. 60). Anjana *et al.*[61], assessed the pattern of PA in the ICMR-INDIAB study, in four regions of India (TN, Maharashtra, Jharkhand and Chandigarh). Of the 14,227 individuals studied, 54.4% was inactive. When extrapolated to the whole country, the estimated number of inactive individuals in India would be 392 million. Subjects were more inactive in urban compared to rural areas (65% versus 50%).

Regular PA is associated with a reduced incidence of diabetes in high-risk groups[62] and it may also slowdown the progression of prevalent disease. In individuals with T2DM, exercise improves glucose tolerance and insulin sensitivity[63]. Skerrett and Manson[64] have reported that physically active individuals have a 30–50% lower risk of developing T2DM compared to sedentary individuals. It has been shown that PA may prevent or delay the onset of T2DM through favourable effects on body weight, insulin sensitivity, glycaemic control, lipid profile, fibrinolysis, blood pressure, endothelial function and inflammatory defence systems[65]. Large randomized clinical trials provide evidence that supervized exercise programmes, with or without dietary modifications, play a significant role in the prevention of diabetes and other NCDs[66–72].

In India, a few trials have been conducted to assess the benefits of PA in T2DM[72,73]. Recently, the Diabetes Community Lifestyle Improvement Program (D-CLIP), a randomized, controlled, translation trial of 578 overweight/obese Asian Indian adults with prediabetes (impaired glucose tolerance or impaired fasting glucose, or both) compared standard care to a culturally tailored lifestyle education curriculum based on the US DPP, plus stepwise addition of metformin (500 mg, twice daily). During three years of follow-up, 34.9% in the control group and 25.7% in the intervention group developed diabetes; the relative reduction in diabetes incidence was 32%, and the number needed to treat to prevent one case of diabetes with the D-CLIP intervention was 9.8 (ref. 72). Table 2 provides evidence for exercise and prevention of diabetes[66–72]. Evidence also exists that interventions applied to people with impaired glucose tolerance are cost-effective and can reduce diabetes complications, such as cardiovascular mortality and retinopathy, and can also improve the quality of life[73].

Evidence suggests that individuals who are active have a lower risk of developing T2DM compared to those who are sedentary. The Nurses' Health Study, surveyed 70,102 female nurses aged 40–65 years in 11 US states in

Table 1. Health benefits of physical activity

↑	Cardiorespiratory fitness	↓	Mortality
↑	Healthier body mass and composition	↓	Cardiovascular disease
↑	Bone health	↓	Stroke
↑	Functional health	↓	Blood pressure
↑	Cognitive function	↓	Cholesterol or triglycerides
↑	HDL cholesterol	↓	Type-2 diabetes and obesity
↑	Growth of new neurons in the brain	↓	Metabolic syndrome
↑	Immune system	↓	Colon and breast cancer
↑	Muscular strength	↓	Depression and anxiety
↑	Sleep	↓	Falls

1986, to examine the relationship of total PA and incidence of T2DM in women. The study reported that walking briskly for at least 30 min/day for 5 days/week was associated with a 25% reduction in diabetes over 8 years of follow-up among those reporting no vigorous exercise, even after adjusting for age, body mass index and other risk factors for diabetes[74]. The findings of a systematic review which evaluated the evidence for an association between PA of moderate intensity and risk of T2DM showed that adherence to recommendations to participate in PAs of moderate intensity such as brisk walking can substantially reduce the risk of T2DM[75].

Built environment

BE is one of the environmental factors that influence lifestyle and habits of its inhabitants, including opportunities for PA, food, rest, relaxation and sleep. In recent years, there has been a marked increase in studies about BE, physical inactivity and development of diabetes. The built or physical environment is the general term used in the literature to describe those objective and subjective features of the physical setting in which people spend their time[76]. According to WHO, BE incorporates the building and transportation design of a city, including factors such as open green spaces, bike ways/sidewalks, shopping centres, business complexes and residential accommodation[77]. BE has three major dimensions which include land-use patterns, that refer to the spatial distribution of human activities, the transportation system and services that provide the spatial links or connectivity among activities and urban design features, including the aesthetic, physical and functional qualities of BE, such as the design of buildings and streetscapes, and relates to both land-use patterns and the transportation system. Other features of BE include: (i) location, density and mix of land use, street layout and connectivity; (ii) physical access to public services, employment, local fresh food and other services; (iii) safety and security; (iv) open and green space; (v) affordable and energy-efficient housing; (vi) air quality and noise; (vii) resilience to extreme weather events and climate change, and (viii) transport.

Evidence shows that urban design settings and various aspects of BE can also play an important role in the development of diabetes and its risk factors[78]. Studies of BE acknowledge that aspects of physical surroundings can shape choices about diet and PA, both important contributors to the development of diabetes. A 5-year follow-up study found that better neighbourhood resources, based on a composite score for healthy foods and PA, were associated with a 38% lower incidence of T2DM[79].

A highly comprehensive study of diabetes and neighbourhood environments was conducted in 140 Toronto neighbourhoods, which assessed the relationship between diabetes and factors such as socio-economic status, ethnic composition, crime rates, car ownership, public transportation, access to healthy food, opportunities for PA, and access to healthcare and other services. The results showed that neighbourhoods with high rates of diabetes tended to have a higher proportion of visible minorities, immigrants and residents with low socio-economic states[80]. Recently a population-based retrospective cohort study was conducted to assess the impact of neighbourhood walkability on diabetes incidence among immigrants (n = 214,882) relative to long-term residents (n = 1,024,380) aged 30–64 years who were free of diabetes in Toronto, Canada. The study concluded that neighbourhood walkability was a strong predictor of diabetes incidence independent of age and income, particularly among recent immigrants. Diabetes incidence varied threefold between recent immigrants living in low-income/low-walkability areas (16.2 per 1000) and those living in high-income/high-walkability areas (5.1 per 1000)[81].

In a community-based study conducted in Chennai, South India, standard lifestyle advice (e.g. increasing PA and improving diet) was provided to the participants at baseline. After a 10-year follow-up, a 277% increase in the exercise levels of residents of a middle-income colony (the Asiad Colony) was reported, following the construction of a park by the residents themselves[82]. During the follow-up period, in a colony of individuals from a lower income group, where no built intervention was given, the prevalence of diabetes increased from 6.5% to 15.3% (a 135% increase). However, in the Asiad Colony, a middle-income group where the park was made available, the prevalence only increased modestly from 12.4% to 15.4% (i.e. 24% increase)[83]. This indicates that a

Table 2. Evidence for exercise and prevention of diabetes

Study	Period	Study subjects	Follow-up (years)	Interventions	Results (cumulative incidence of diabetes; %)	Risk reduction (%)
Malmö feasibility study[66]	1985–1990	222 subjects with early-stage type-2 and IGT aged 47–49 years	6	Diet and exercise	Controls – 28.6 Diet and exercise – 10.6	Diet and exercise – 59%
DA Qing IGT and diabetes study[67]	1986–1992	577 subjects with IGT aged >25 years	6	Control Diet Exercise Diet and exercise	Controls – 68 Diet – 44 Exercise – 41 Diet and exercise – 46	– Diet – 31 Exercise – 46 Diet and exercise – 42
Finnish diabetes prevention study[68]	1993–1998	522 overweight subjects with IGT aged 40–64 years	4	Control Diet and exercise	Controls – 23 Diet and exercise – 11	– Diet and exercise – 58
Diabetes prevention programme[69]	1996–1999	3234 overweight subjects with IGT aged >25 years	2–8 (study terminated 1 year earlier than planned)	Placebo Metformin Lifestyle	Controls – 11 Metformin – 7.8 Lifestyle – 4.8	– Metformin – 31 Lifestyle – 58
Indian diabetes prevention programme[70]	2001–2002	531 Subjects with IGT aged 35–55 years	2.5	Placebo metformin Lifestyle metformin and lifestyle	Controls – 55 Metformin – 40.5 Lifestyle – 39.3 Metformin and lifestyle – 39.5	Metformin – 26.4 Lifestyle – 28.5 Metformin and Lifestyle – 28.2
Japanese trial[71]	1999–2004	458 men with IGT	4	Control metformin and lifestyle	Controls – 9.3 Metformin and lifestyle – 3.0	Diet and exercise – 67.4
Diabetes community lifestyle improvement program[72]	2009–2012	578 overweight/obese subjects with prediabetes	3	Control Metformin and lifestyle	Control group – 34.9 Metformin and lifestyle – 25.7%	Metformin and lifestyle – 32

IGT, Impaired glucose tolerance.

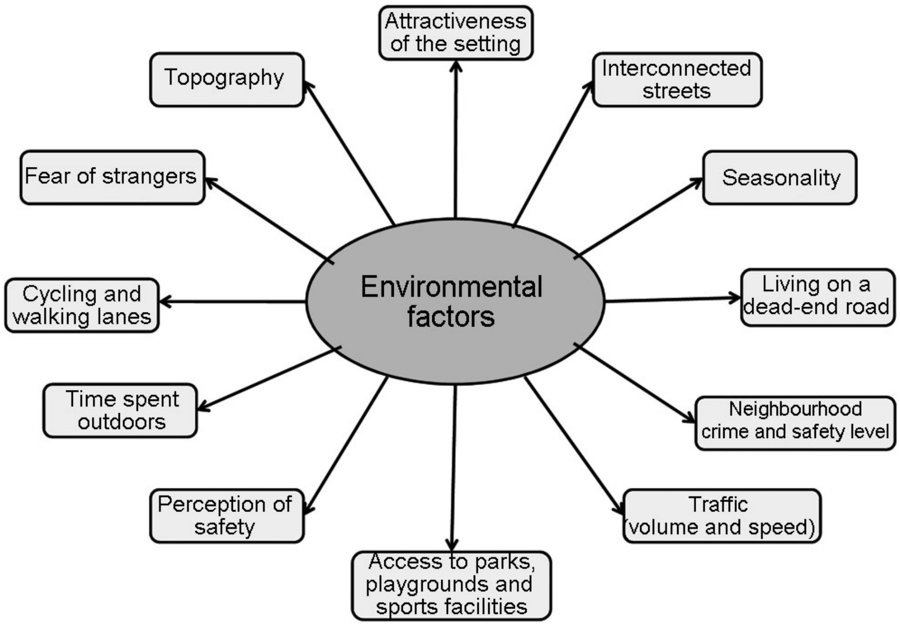

Figure 3. Environmental factors influencing the level of physical activity.

moderate investment of time and effort might slowdown the rise in the prevalence of diabetes.

With changing trends in terms of globalization, economic liberalization and urbanization with large populations undergoing migratory transitions, there is substantial reduction in the physical requirements of daily life due to consequent decline of physically active occupations, with more labour-saving devices at home, and the dominance of automobiles for personal travel. Lifestyle and cultural changes, such as increases in television viewing time and other sedentary activities, have also played a role in reducing PA. In addition, evidence also suggests that BE can facilitate or constrain PA[84,85]; however, most of the studies conducted thus far have been primarily limited to Western countries[86]. Environmental changes have been identified as potentially effective population-level PA promotion strategies because they can potentially affect the behaviour of a large number of people for a sustained amount of time[87]. Figure 3 illustrates the environmental factors that influence the level of PA.

A cross-sectional study conducted among 6968 adults in 16 cities located in Belgium, Brazil, Colombia, Czech Republic, Denmark, China, Mexico, New Zealand, Spain, United Kingdom and USA, assessed the associations of perceived environmental attributes with objectively measured PA outcomes. Perceived land-use mix – access and diversity, street connectivity, pedestrian infrastructure and safety, aesthetics, safety from crime, few cul-de-sacs, and lack of barriers to walking were all positively associated with PA outcomes in the pooled, site-adjusted, single-predictor models, while aesthetics and land-use mix – access were significant predictors of PA outcomes in the fully adjusted models[88]. Several studies have identified numerous BE characteristics associated with PA, including access to facilities, aesthetic quality of facilities and neighbourhoods, land-use mix, and issues of safety from traffic and crime[84,89–91].

A recent study by Sallis *et al.*[92] which included 6822 adults aged 18–66 years from 14 cities in 10 countries from the International Physical Activity and Environment Network (IPEN), reported that people who live in activity-friendly neighbourhoods perform up to 90 min more exercise per week. The difference in PA between participants living in the most and least activity-friendly neighbourhoods ranged from 68 to 89 min/week, representing 45–59% of the recommended 150 min/week. The four neighbourhood features which were most strongly associated with increased PA were high residential density, number of intersections, number of public transport stops, and number of parks within walking distance even after controlling for factors like age, gender, education, marital and employment status, and income status. The activity-friendly characteristics applied across cities, suggesting that they are important design principles that can be applied internationally. Another study from the IPEN group which examined the association between adolescent and parental perceptions of neighbourhood safety and adolescents' PA reported that parents' perceptions of traffic, stranger danger, and crime safety were all related to adolescents' active transportation[93]. It is estimated that the total health gained by changing to optimal activity-friendly environments will be close to 2 million fewer deaths and around 3% fewer NCDs[94].

Conclusion

It is now well conceived that altering BE and designing healthier cities can encourage greater activity and improve health. For example, diabetes prevalence/ incidence can be reduced in areas where there is land-use mix (i.e. the area has a mix of residential, commercial, office and institutional uses), and also where streets are 'pedestrian permeable'. At the street level, walking can be increased in neighbourhoods by providing pavements, undertaking motor-traffic reduction strategies, increasing good street connectivity and improved perceived neighbourhood safety. At the community level, accessibility to and availability of adequately wide, useable, unencroached pedestrian pathways, parks, green space, playgrounds and recreation areas can encourage walking. Improving aesthetics and the safety of parks, leisure facilities and open spaces further enhances attendance and usage of these facilities. Furthermore, design of workplaces, stairwells and school playgrounds can positively influence PA levels.

Implementing these changes to BE to positively influence health outcomes and to be made more activity-friendly will require the collaboration of health professionals with diverse sectors of Government and society, including city planning, transportation, parks and recreation, and real-estate development. Health professionals have a responsibility to become informed advocates for creating healthier environments.

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